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Active removing of unabsorbed phonon energy in acousto-optic devices

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1. Introduction

The work is devoted to the study of acoustic energy removal from an acousto-optic devices with high energy consumption. The research vector is caused by the following circumstance.

Recent years there has been the creation of new high-power pulsed lasers of the mid-IR range (Ho^{3+}:YAG, 2 μm range; Fe^{2+}:ZnS, 3-5 μm range [1-3]) operating in Q-switching mode or using Q-switching pumping laser system. Acousto-optic (AO) laser Q-switches based on fused or crystalline quartz with an efficiency of about 50% on mid-IR require extremely high RF power consumption of 50-150 W. The usual solution, water cooling or conductive Peltier cooling, is not efficient. In low freguency AO devices there are two main sources of heat: transducer and acoustic absorber. In any case, the passive BAW absorber is located on the Q-switch housing inside the laser resonator, and can cause temperature instability of the latter due to AO crystal overheating.

We proposed a new method to remove the absorber from the resonator and place it in a structurally acceptable zone outside the laser using a cable and a matched load. The method is based on the conversion of BAW energy into electrical energy by the second, receiving, transduser.

2. Theoretical study

The receiving structure is shown in **Fig. 1**. The receiving transducer is loaded onto an external electrical circuit having complex impedance.

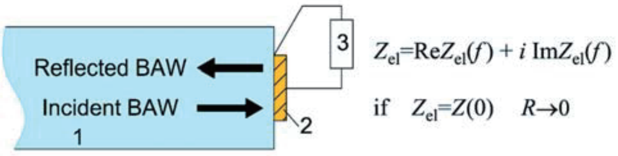

Fig.1 Receiving transducer structure. 1-AO crystal, 2-piezotransducer, 3- electrical RL load.

The BAW falls from a bulk crystal to the boundary crystal-transducer and, due to the piezoelectric effect, excites the electrical oscillations in the circuit. Oscillations reach the maximum near the resonant frequency ω_0 of the circuit. At the matching conditions $Zel=Z(0)$ the acoustic reflection coefficient $R(\omega/\omega_0)$ decrease to zero. As an example we consider longitudinal wave propagating in paratellurite (TeO_2) in the standard geometry of isotropic AO interaction and lithium niobate (LN) transducer.

In the plane wave approximation, it is shown that with a certain choice of the complex load, the acoustic reflection $R(\omega/\omega_0)$ from the TeO_2-LN boundary at the central frequency ω_0 tends to zero (**Fig. 2**).

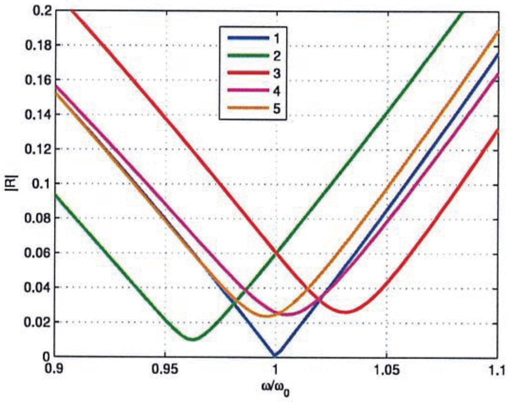

Fig.2 Frequency dependence of the reflection coefficients $R(\omega/\omega_0)$ at different values of the electrical inductive load Zel. Curve 1 - $Zel = Z(0)$ corresponds to the optimal load complex value (matching inductive electrical load); 2 - Zel = Re $Z(0)$ + j0.95Im $Z(0)$; 3 - Zel = Re $Z(0)$ + j1.05Im $Z(0)$; 4 - Zel = 0.95Re $Z(0)$ + jIm $Z(0)$; 5 - Zel = 1.05Re $Z(0)$ + jIm $Z(0)$.

3. Experiment: verification of the principle.

For experimental verification, a TeO_2 based AO device with two oppositely placed identical piezotransducers was fabricated. The distance between the generating and receiving transducer is

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8.5 mm. The transducers resonant frequencies were 85 MHz. The scheme of the AO device is presented in **Fig. 3**.

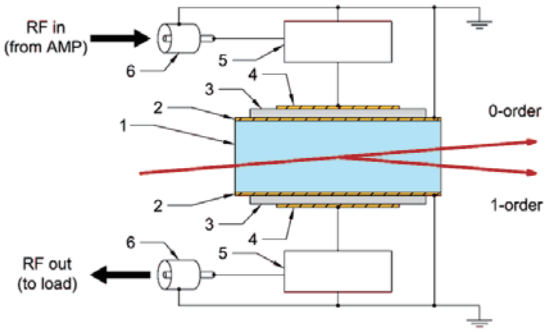

Fig.3 Experimental AO device. 1 - TeO2 crystal; 2 - intermediate electrode; 3 - LN transducer; 4 - electrode; 5 - matching circuit; 6 – connector.

The Agilent N8241A generator supplied single-frequency pulses through an Amplifier Research 25A250A amplifier to the first transducer. The matched load of 50 Ohms was connected to the second transducer. The first acoustic pulse in **Fig. 4** is incoming, the second is reflected.

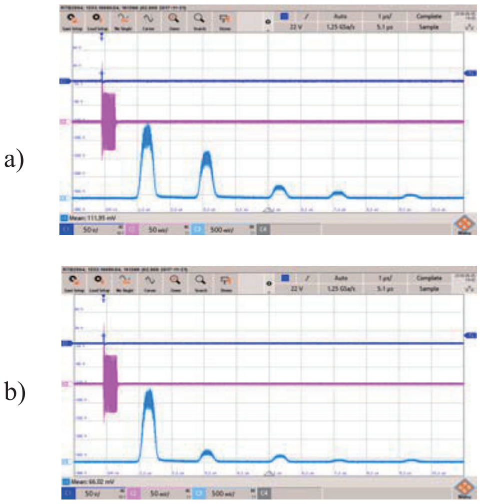

Fig.4 Optical response AO device, a) without load on the receiving transducer; b) with matched 50 Ohm load on the receiving transducer.

In the absence of the electrical load on the receiving transducer, the diffraction efficiency for the reflected BAW is 60% of the efficiency of the incident wave (**Fig. 4a**). When a matched load of 50 Ohms is connected to the receiving transducer, the reflected BAW is substantially reduced: the intensity of the second pulse in the diffraction pattern decreases 6 times (10%) (**Fig. 4b**).

4. Experiment: BAW energy removal.

We designed and fabricated a Q-switch based on quartz crystal with two LN transducers. The transducers' complex impedance is transformed by the matching circuit to the optimal value of 50 Ohms. In the experiment, a 50 Ohm load was located outside the AO device and connected by the cable, **Fig. 5**.

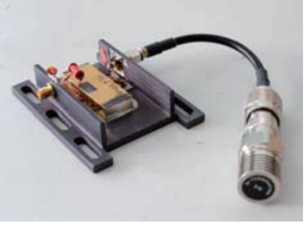

Fig.5 Experimental device with 50 Ohm load as absorber

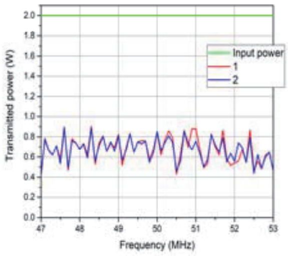

Fig.6 RF power removed from the AO device vs frequency

Both the incoming and the removed RF power were measured by the power meter. The frequency dependence of the RF power removed from the AO Q-switch is presented in **Fig. 6**. The RF driving power supplied to the generating transducer was kept constant. In the frequency band 50±3 MHz the removed RF power is 1/3 of the driving power. Total insertion losses in the conversion of electrical energy into acoustic energy and vice versa are 2/3 of the RF driving power. The insertion losses of each transducer are less than 2,5 dB. Curve 1 and curve 2 in **Fig. 6** correspond to the cases when the generating and receiving transducers are swapped.

5. Conclusion

The verification of the principle showed that more than the 1/2 part of BAW energy can be removed from AO crystal of the device by means of receiving transducer and RF cable outside the optical zone. Further development of this method will allow expanding the scope of AO devices in the middle IR range.

Acknowledgment
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